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<b>TRANSMITTAL LETTER TO THE UNITED STATES          DESIGNATED/ELECTED OFFICE (DO/EO/US)          CONCERNING A FILING UNDER 35 U.S.C. 371</b>				U.S. APPLICATION NO. (If known, see 37 CFR 1.5) <b>10/089712</b>	
INTERNATIONAL APPLICATION NO. <b>PCT/JP00/06721</b>		INTERNATIONAL FILING DATE <b>28 September 2000</b>		PRIORITY DATE CLAIMED <b>01 October 1999</b>	
TITLE OF INVENTION <b>MAGNETIC RESONANCE IMAGING APPARATUS AND METHOD</b>					
APPLICANT(S) FOR DO/EO/US <b>Tetsuhiko TAKAHASHI, Kenji TAKIGUCHI, Masahiro TAKIZAWA</b>					
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.					
1. <input checked="" type="checkbox"/> This is a <b>FIRST</b> submission of items concerning a filing under 35 U.S.C. 371. 2. <input type="checkbox"/> This is a <b>SECOND</b> or <b>SUBSEQUENT</b> submission of items concerning a filing under 35 U.S.C. 371. 3. <input checked="" type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below. 4. <input type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31). 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2)) a. <input checked="" type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau). b. <input type="checkbox"/> has been communicated by the International Bureau. c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US). 6. <input checked="" type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)). a. <input checked="" type="checkbox"/> is attached hereto. b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4). 7. <input type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)) a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau). b. <input type="checkbox"/> have been communicated by the International Bureau. c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired. d. <input type="checkbox"/> have not been made and will not be made. 8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)). 9. <input checked="" type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). 10. <input type="checkbox"/> An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).					
<b>Items 11 to 20 below concern document(s) or information included:</b>					
11. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98. 12. <input checked="" type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included. 13. <input type="checkbox"/> A FIRST preliminary amendment. 14. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment. 15. <input type="checkbox"/> A substitute specification 16. <input type="checkbox"/> A change of power of attorney and/or address letter. 17. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825. 18. <input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4). 19. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4). 20. <input checked="" type="checkbox"/> Other items or information. <b>6 drawing sheets (Figs. 1-6), copy of PCT Publication No. WO 01/24695, Communications from the International Bureau (including Notice Informing The Applicant Of The Communication Of The International Application To The Designated Offices, and Notification Of Transmittal Of Copies Of Translation Of The International Preliminary Examination Report)</b>					

U.S. APPLICATION NO (if known, see 37 CFR 1.5) <b>PCT/JP00/06721</b>		INTERNATIONAL APPLICATION NO <b>28 September 2000</b>		<div style="text-align: right;"> <b>70/089712</b>  <b>JG13 Rec'd PCT/PTO 01 APR 2002</b> </div>	
				ATTORNEY'S DOCKET NUMBER <b>1141/67087</b>	
21 <input checked="" type="checkbox"/> The following fees are submitted: <b>BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):</b> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO ..... <b>\$1040.00</b>  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... <b>\$890.00</b>  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... <b>\$740.00</b>  International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... <b>\$710.00</b>  International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) ..... <b>\$100.00</b>  <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>CALCULATIONS PTO USE ONLY</b>          <div style="border: 1px solid black; padding: 2px; margin-top: 10px;"> <b>\$890.00</b> </div>	
Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	\$	
Total claims	<b>20 - 20 =</b>	<b>0</b>	x <b>\$18.00</b>	<b>\$0</b>	
Independent claims	<b>6 - 3 =</b>	<b>3</b>	x <b>\$84.00</b>	<b>\$252.00</b>	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ <b>\$280.00</b>	<b>\$280.00</b>	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				<b>\$1,422.00</b>	
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				\$	
<b>SUBTOTAL =</b>				<b>\$1,422.00</b>	
Processing fee of <b>\$130.00</b> for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$	
<b>TOTAL NATIONAL FEE =</b>				\$	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). <b>\$40.00</b> per property +				<b>\$40.00</b>	
<b>TOTAL FEES ENCLOSED =</b>				<b>\$1,462.00</b>	
				Amount to be refunded:	\$
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a. <input checked="" type="checkbox"/> A check in the amount of \$ <b>1,462.00</b> to cover the above fees is enclosed.  b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.  c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <b>03-3125</b> . A duplicate copy of this sheet is enclosed.  d. <input type="checkbox"/> Fees are to be charged to a credit card. <b>WARNING:</b> Information on this form may become public. <b>Credit card          information should not be included on this form.</b> Provide credit card information and authorization on PTO-2038.					
<b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR          1.137 (a) or (b)) must be filed and granted to restore the application to pending status.</b>					
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<b>40,837</b> REGISTRATION NUMBER					

6/pvts 1

Magnetic resonance imaging apparatus and method

Technical field

The present invention relates to a magnetic resonance  
 5 imaging (MRI) apparatus for imaging nuclear density  
 distribution or relaxation time distribution by measuring  
 nuclear magnetic resonance (NMR) signals emitted from  
 hydrogen atoms or phosphorus atoms in an examined object.

10 Background of Invention

An EPI (echo planar imaging), burst sequence and the  
 like have been known as a fast imaging method using an MRI  
 apparatus, where a plurality of echo signals is measured at  
 one excitation of spins, and are used for a three-  
 15 dimensional measurement or functional measurement in which  
 many images are obtained continuously. As an application of  
 these methods, a multi-shot EPI that measures a set of data  
 at a plurality of shots (excitation) has been also known.

Echo signals obtained by such a fast imaging method  
 20 are likely to be influenced by eddy currents caused by  
 gradient magnetic fields or inhomogeneities in a static  
 magnetic field, and therefore are subjected to phase  
 correction using a correction data (for example, Japanese  
 Patent Application Kokai 5-31095). For the correction data,  
 25 scan data obtained by performing a measurement (pre-scan)  
 similar to a main measurement is used. The pre-scan is  
 carried out prior to the main measurement without a slice-  
 encoding gradient magnetic field or a phase-encoding  
 gradient magnetic field.

An SSFP (Steady State Free Precession) measurement has been also known as an application of MRI. The SSFP measurement obtains echo signals successively with a short repetition time TR relative to a longitudinal relaxation time of an examined object while changing a slice-encoding gradient magnetic field or phase-encoding gradient magnetic field. The resulting echoes are in a steady state free precession.

The SSFP measurement is suitable for a three-dimension measurement, since it measures echoes with a short repetition time while changing a condition of applying gradient magnetic fields, and its combination with the fast imaging method such as EPI is proposed (for example, SSFP-EPI).

The inventors of the present invention tried to apply the aforementioned signal correction using correction scan data to the SSFP-EPI. However, it was found that good correction results could not be obtained and artifact appeared in images. The reason would be thought as follows.

In correction using the pre-scan data, conditions such as eddy currents and inhomogeneities in the static magnetic field should be the same at a time of acquisition of the pre-scan data and a time of acquisition of data for forming images (main scan data). However, eddy currents, which generate at gradient magnetic field coils, vary according to a time constant. The variations of eddy currents are not a serious problem in a measurement with a long repetition time but are problematic in the SSFP measurement because of its short repetition time. In addition, since a phase

rotation amount of spins also depends on a degree of saturation of spins, it can be changed gradually till spins become to be in a steady state in the SSFP-EPI. Such phase changes continuing till the steady state cannot be  
5 corrected by the conventional phase correction method using the pre-scan data.

Accordingly, an object of the present invention is, in the SSEP measurement, to eliminate essential causes of artifacts due to change of physical phenomena over time  
10 such as eddy currents by gradient magnetic fields, variations of residual magnetic field, and to provide MR images having good quality and no artifact.

#### Disclosure of Invention

15 In order to solve the above-mentioned problems, an MRI apparatus of the present invention performs a pre-scan for obtaining data for correcting variations of static magnetic field inhomogeneities and/or eddy currents prior to a main measurement scan, and corrects data obtained by  
20 the main measurement scan based on data obtained by the pre-scan.

Specifically, the MRI apparatus of the present invention comprises magnetic field generating means for producing nuclear magnetic resonance in an object to be  
25 examined, detecting means for detecting nuclear magnetic resonance signals emitted from the object, control means for controlling the magnetic field generating means and detecting means, computing means for visualizing morphology or functions of the examined object using the nuclear

magnetic resonance signals detected by the detecting means,  
 and a display means for displaying the computed results as  
 images, wherein the control means operates so that a  
 plurality of correction data are acquired periodically at a  
 5 predetermined interval and image-forming data are  
 continuously acquired between acquisitions of the  
 correction data, and the computing means produces a  
 correction data group, which corresponds to acquisition  
 time of the image-forming data, using the correction data  
 10 and corrects the image-forming data using the correction  
 data group corresponding to the acquisition time.

The MRI apparatus of the present invention comprises  
 magnetic field generating means for producing nuclear  
 magnetic resonance in an object to be examined, detecting  
 15 means for detecting nuclear magnetic resonance signals  
 emitted from the object, control means for controlling the  
 magnetic field generating means and detecting means,  
 computing means for visualizing morphology or functions of  
 the examined object using the nuclear magnetic resonance  
 20 signals detected by the detecting means, and display for  
 displaying the computed results as images, wherein the  
 control means continuously performs a step of acquiring a  
 plurality of nuclear magnetic resonance signals as image-  
 forming data at one excitation and also performs a step of  
 25 acquiring correction data a number of times at a desired  
 interval during the continuous steps, and the computing  
 means comprises means for producing a correction data group,  
 which includes changes during the interval, using a  
 plurality of the correction data acquired at a desired

interval and means for correcting image-forming data using a correction data from among the correction data group corresponding to acquisition time of the image-forming data.

An MRI method of the present invention comprises a  
 5 step A of acquiring image-forming data consisting of a plurality of nuclear magnetic resonance signals at one excitation, a step B of repeating the step A while changing a slice-encoding gradient magnetic field and/or phase-encoding gradient magnetic field, a step C of repeatedly  
 10 acquiring correction data at a desired interval during repetition of the step A, a step D of producing correction data corresponding to acquisition time of image-forming data acquired between acquisition of one correction data and acquisition of the next correction data using at least  
 15 two correction data, and a step E of correcting the image-forming data using correction data from among the correction data produced in the step D, which corresponds to acquisition time of the image-forming data.

The interval of acquiring the correction data may be  
 20 the same as a time required for collecting image-forming data of one image or may be a time required for collecting image-forming data of plural images.

According to the MRI apparatus and method, correction data including temporal variations between acquisition of  
 25 one correction data and acquisition of the next correction data is produced. When plural image-forming data are acquired between these two correction data, each of the image-forming data is corrected using correction data corresponding to its acquisition time (estimated correction

data).

Thus, the image-forming data consisting of a plurality of nuclear magnetic resonance signals is corrected using corresponding correction data including temporal variations from among the correction data group, and consequently phase correction can be done taking account of temporal variations of physical phenomena such as influence of spin saturation, eddy currents by gradient magnetic fields, changes of residual magnetic fields so that artifact caused by the phenomena can be prevented.

The plural correction data are preferably acquired without a phase-encoding magnetic field, or acquired while imparting with a phase-encoding magnetic field and readout magnetic field having a polarity opposite to that used for main scan data. When the phase-encoding magnetic field is not applied, the correction data consists of nuclear magnetic resonance signals of the same number as that of image-forming data obtained in the step A. When the phase-encoding magnetic field is applied, the correction data consists of nuclear magnetic resonance signals of the same number as the phase-encode number for the image-forming data. In this specification, these two are referred as correction scan data.

In a preferred embodiment of the present invention, the step B is carried out with a repetition time significantly shorter than a longitudinal relaxation time of the examined object. This enables to obtain a series of main scan data in a steady state free precession.

In this case, each of correction scan data is



acquired preferably with a interval equal to the  
aforementioned TR before and after acquisition of main scan  
data. As a result, a steady state free precession can be  
maintained during acquisition of the correction scan data  
5 and degradation of image contrast can be prevented.

#### Brief explanation of drawings

Figure 1 is a schematic view of an embodiment of the  
MRI method of the present invention. Figure 2 is a  
10 flowchart of signal processing according to the MRI method  
of the present invention. Figure 3 is a timing chart of an  
EPI sequence to which the present invention is applied.  
Figure 4 is an overall diagram of an MRI apparatus to which  
the present invention is applied. Figure 5 is a flowchart  
15 of signal processing according to another embodiment of the  
MRI method of the present invention. Figure 6 is a  
schematic view of another embodiment of the MRI method of  
the present invention.

#### 20 Preferred embodiment of Invention

Preferred embodiments of the present invention will  
now be explained hereinafter. Figure 4 is an overall  
diagram of an MRI apparatus to which the present invention  
is applied. The MRI apparatus comprises a magnet 402  
25 generating a static magnetic field in a space around an  
object to be examined (patient) as magnetic field  
generating means, gradient magnetic field coils 403 which  
generate gradient magnetic field in the space, an RF coil  
404 for generating a high frequency magnetic field in an

area within the object, and an RF probe 405 for detecting MR signals emitted from the object 401. In addition, it is provided with a signal processor 407 for processing the detected MR signals to transform to image signals, a display 408 for displaying images showing morphology, function and spectrum of the object based on the image signals inputted from the signal processor 407, and a bed 412 on which the patient lies.

The gradient magnetic field coils 403 consist of gradient magnetic field coils of three direction X, Y, Z, each of which generates a gradient magnetic field corresponding to signals from a power supply 409. The RF coil 404 generates a high frequency magnetic field corresponding to signals from an RF transmitter 410. Signals from the RF probe 405 are detected by a signal detector 406 and processed by the signal processor 407. The power supply for gradient magnetic field 409, RF transmitter 410 and signal detector 406 are controlled by a controller 411 according to a timing chart called a pulse sequence.

In the MRI apparatus of this embodiment, the controller 411 performs a fast imaging sequence according to a multi-shot EPI. Specifically, a pulse sequence in which a plurality of nuclear magnetic resonance signals for image-forming data is acquired at one excitation is repeated to collect a series of image-forming data (main scan data). During acquisition of a series of the main scan data, application of an RF magnetic field and gradient magnetic fields and acquisition of signals are controlled

so that correction scan data are obtained at an approximately same interval (referred simply as same interval). The repetition time TR is so determined that a series of the scan data (main scan data and correction scan data) can be obtained in a steady state free precession.

The signal processor 407 performs ordinary signal processing required for image reconstruction and, in addition, has a function of producing correction data including temporal changes using a plurality of correction scan data obtained at a predetermined interval and a function of correcting main scan data using correction data corresponding to acquisition time of the main scan data.

The display 408 displays images produced by reconstruction of the main scan data which has been corrected using correction data.

Next, an embodiment of the MRI method of the present invention, which is applied to a two-dimensional SSFP-EPI, will be explained. Figure 1 is an explanatory view of data acquisition and correction in this embodiment, where the axis of abscissas is time. In Figure 1, a number 13 indicates a Fourier transform in the readout direction, a number 14 indicates phase correction and a number 16 indicates a Fourier transform in the phase-encoding direction. Figure 2 is a flowchart showing procedures conducted by the signal processor 407.

In the measurement, a first pre-scan (scan for obtaining correction data, referred as correction scan hereinafter) is carried out prior to a main measurement to obtain correction scan data 11. Then the main measurement

is carried out to obtain main scan data 12 (121, 122, 123, 124) (step 64). During the continuous measurement of main scan data 12, a second, third...correction data 11 (111, 112, 113...) are repeatedly acquired at a fixed interval (step 5 61). These correction scan data 11 are used for phase correction of main scan data (steps 70, 62, 63), which will be explained later.

A pulse sequence used for the main measurement may be, for example, an EPI sequence shown in Figure 3. That is, an 10 RF pulse 201 is applied to an object to be examined, which includes detectable magnetization, together with a gradient magnetic field pulse 202 for selecting a slice to be imaged. Then, a pulse 203 for imparting a phase-encoding offset and a pulse 205 for imparting a readout gradient magnetic field 15 offset are applied. Thereafter, gradient magnetic field pulses 206 with alternating polarity are applied successively.

A shape of the gradient magnetic field pulse 206 is trapezoid. Simultaneously with the gradient magnetic field 20 pulses 206, discrete phase-encoding gradient magnetic field pulses 204 are applied. Phase-encoded echo signals 207 are generated in each period of alternating readout gradient magnetic fields 206 and are collected as a sample during a time range 208 to obtain time-series data. Although five or 25 more of echo signals are acquired in Figure 3, the number  $n$  of signals can be less.

Provided that a number of echo signals measured at one excitation (one shot) is  $n$  and a number of data in the phase-encoding direction is  $N$ , one set of two-dimensional

data can be obtained by  $N/n$  time repetitions ( $N/n$  shots) of the sequence shown in Figure 3.

In the correction scan, echo signals of the same number are measured using a similar sequence shown in Figure 3 without a phase-encoding gradient magnetic field  $G_e$ . Alternately, correction scan data may be acquired by applying phase-encoding gradient magnetic fields together with reversed readout gradient magnetic field  $G_r$ . In this case, correction scan data of the same number as the shot number of the main measurement are acquired.

In the embodiment shown in Figure 1, a set of two-dimensional data is obtained by 10 shots and one correction scan data 11 is obtained every 10 shots. An interval of obtaining the correction scan data 11 may be shorter or longer than in this embodiment.

The repetition time of the correction scan data 11 and that of main scan data 12 should be fixed and significantly shorter than a longitudinal relaxation time of spins, for instance, about 10ms.

Next, based on the thus periodically obtained plural correction data, a estimated phase rotation amount 19 for each acquisition time of the main scan data is calculated (step70). This calculation may be done by linear interpolation using adjacent correction scan data or may be done by a known interpolation technique. This calculation provides a group of correction data (correction data group), which consists of estimated correction data for each acquisition time of the main scan data. In the illustrated example, estimated correction data corresponding to main

scan data of 10 shots acquired between acquisitions of the correction scan data 111 and 112 are obtained.

In the next step, for the correction data group, data arrangement is reversed depending on the polarity of the gradient magnetic field pulse (step 62). This is a common process in EPI. In the sequence of Figure 3, for example, the first echo is acquired with a negative polarity gradient magnetic field pulse  $G_r$  and the second echo is acquired with a positive polarity gradient magnetic field pulse  $G_r$ . Accordingly, arrangement of the first echo with a negative polarity is reversed in the time direction and that of the second echo is not reversed.

After the abovementioned reversal, the correction data is subjected to a Fourier transform in the readout direction for each echo and stored in a memory of the signal processor 407 as a complex data map on a two-dimensional hybrid space (position in the readout direction vs echo acquisition order) (step 63).

For the main scan data, similarly to the correction scan data, data arrangement is reversed for each echo depending on the polarity of the gradient magnetic field pulse (step 65). Then, each echo is subjected to a Fourier transform 13 in the readout direction and stored in a memory of the signal processor 407 as a complex data map on a two-dimensional hybrid space (step 66).

Thereafter, the Fourier transformed main scan data is corrected using the Fourier transformed correction data. In the phase correction 14, the correction data corresponding to acquisition time of the main scan data of each shot is

used (step67). Specifically, the main scan data 121 is corrected with the correction data 191 and the main scan data 122 is corrected with the correction data 192 respectively to obtain the corrected main scan data 15.

5 Such phase correction enables to eliminate influence of inevitably unsatisfactory instrumental adjustment at the signal acquisition moment such as residual offset components of gradient magnetic fields, inhomogeneities in the static magnetic field caused by an object under  
10 examination. Particularly, since a phase rotation amount at the acquisition time of main scan data is estimated and the estimated value is used for correction of the main scan data, variations of the phase rotation depending upon a degree of spin saturation can be corrected. In addition,  
15 even when phase variations caused by eddy currents of gradient magnetic fields or static magnetic field inhomogeneities change over time, correction can be done accurately.

Finally, 10 sets of the corrected main scan data 151,  
20 152, 153...are collected and subjected to a Fourier transform 16 in the phase-encoding direction to obtain a two-dimensional MR image (step 68) and the image is displayed (step 69). The image has good quality since residual offset components of gradient magnetic fields, inhomogeneities in  
25 the static magnetic field caused by an examined object and their variations over time have been corrected.

Since the main scan is carried out continuously between correction scans performed at a predetermined interval, a plurality of two-dimensional MR images can be obtained

successively in a time course. The plural two-dimensional MR images may be images of an identical slice or may be images of different slices. When images of different slices are to be obtained, an RF pulse 201 and/or slice selecting  
5 gradient magnetic field 202 in the pulse sequence of Figure 3 is changed every 10 shots to acquire echo signals 207 from different slices.

If the identical slice is measured successively, images of the slice are successively displayed on the display 408.  
10 These successive images may be utilized for observation of function of an organ. If images of different slices are obtained, the images of plural slices may be displayed simultaneously on the display 408 and thus a broad region can be observed at the same time. These manners of  
15 measurement and displaying of images may be employed in a suitable combination. For example, during a continuous imaging of an identical slice, imaging of an adjacent slice or intersecting slice may be performed, and the successively obtained images of one slice and images of  
20 plural slices may be displayed one by one. Alternately, images of plural slices are displayed simultaneously and repeatedly, and are updated successively.

In the abovementioned embodiment, it has been explained that a phase rotation amount of the main scan data is  
25 estimated for each acquisition time based on the obtained raw correction scan data. However, estimation of the phase rotation amount of the main scan data for each acquisition time can be done based on the correction scan data after a Fourier transform. The flowchart of such procedures is



shown in Figure 5.

In the embodiment shown in Figure 5, the correction scan data is acquired periodically during acquisition of the main scan data similarly to the flowchart shown in Figure 2 (step 61). However, the correction scan data is subjected to a Fourier transform prior to estimation (step 70) of the correction data for the main scan data of each acquisition time. That is, first, reversal of data arrangement is carried out corresponding to the polarity of gradient magnetic field pulse (step 62) and then a Fourier transform of each echo is carried out in the readout direction (step 63).

For the thus Fourier transformed data, correction data corresponding to acquisition time of the main scan data is calculated. This calculation may be also performed by linear interpolation of the Fourier transformed data, which have been acquired before and after the acquisition time of the subjected main scan data.

The thus calculated correction data group is stored as a complex data map on a two-dimensional hybrid space and used for phase correction 14 of the main scan data which has been subjected to the Fourier transform in the readout direction. In the phase correction, the main scan data is corrected using correction data corresponding to acquisition time of the main scan data one by one (step 67). In this case too, similarly to the case of Figure 2, even temporal variations in apparatus characteristics, influence of eddy currents or spin saturation can be corrected precisely.

The MRI method of the present invention has been explained with respect to its application to a two-dimensional measurement. The present invention may be applied to a three-dimensional measurement in the same manner.

Figure 6 shows another embodiment of the MRI method according to the present invention, which is applied to a three-dimensional measurement. This embodiment is same as the embodiment shown in Figure 1 in that the correction scan data 11 is acquired at a predetermined interval during acquisition of the main scan data 12, and that the correction scan data and the main scan data are measured with the same repetition time TR. In the three-dimensional measurement, however, a step of collecting a series of main scan data is repeated while changing intensity of a slice-encoding gradient magnetic field. In the illustrated example, a slice-encode is changed every acquisition of main scan data of 10 shots.

In this embodiment too, a series of the main scan data 12 is corrected based on correction data corresponding to the acquisition time from among the correction data group 19, which are estimated from two correction scan data obtained before and after the acquisition time (for example 111 and 112). The correction data group 19, which is a set of correction data for each acquisition time of the main scan data, may be calculated by interpolation using raw correction scan data as shown in the figure, or may be calculated using the Fourier transformed data obtained by performing a Fourier transform 13 on the raw correction

5 correction 14.

10

25

two-dimensional image shown in Figure 1. However, the main scan data 15 consists of signals from a slab having a certain thickness and the resolution degree of images depends on the slab thickness. Accordingly, when two-dimensional images produced from the main data 15 obtained by the three-dimensional imaging are displayed, the slab thickness should be adjusted suitably.

Although an interval of acquisition of the correction scan data and that of stepping the slice encode are set to be equal in Figure 6, they are not necessarily equal. In a case that more accurate correction is required, a plurality of correction scan data may be acquired within the same slice-encoding step.

In the aforementioned embodiments, a multi-shot EPI has been exemplified but the present invention is similarly applied to a single shot EPI. In the single shot EPI, each of the main scan data 121,122...consists of echoes necessary for forming one image and the correction scan data consists of the same number of echoes.

Similarly to the embodiments of Figures 1 and 6, the correction data corresponding to acquisition time of the main scan data is produced using a series of correction scan data obtained before and after the acquisition of the main scan data, and the main scan data, which has been subjected to a Fourier transform 13 in the readout direction, is phase-corrected (14) using the corresponding correction data. In the single shot EPI, however, the thus corrected scan data 151, 152... can be reconstructed to one image by performing a Fourier transform in the phase-

encoding direction.

If the main scan data is imparted with a slice encode, 3D-image data 18 can be obtained by collecting the data of number equal to the slice-encode number, which has been  
5 subjected to a Fourier transformed in the phase-encoding direction, and by performing a Fourier transform in the slice-encoding direction.

Although the two-dimensional or three-dimensional EPI has been explained hitherto, the present invention can be  
10 applied to any conventional sequence including correction of phase rotation using pre-scan data. For instance, it can be applied to a two-dimensional or three-dimensional multi-shot EPI sequence of Time Reverse type, two-dimensional multi-shot spiral scan sequence, three-dimensional GRSE  
15 (gradient and spin echo sequence), hybrid burst sequence or the like.

#### Industrial applicability of Invention

In a sequence including phase correction using  
20 correction scan data, the correction scan data is obtained periodically and the phase rotation amount at each acquisition time of the main scan data acquired between the adjacent correction scan data is estimated. The main scan data is corrected using the thus estimated phase rotation  
25 amount. As a result, MR images having high quality and no artifact can be obtained even in a condition where the phase variations of signals change due to temporal variations of eddy currents or spin saturation state.

# CLAIMS

1. A magnetic resonance imaging apparatus comprises magnetic field generating means for producing nuclear  
5 magnetic resonance in an object to be examined, detecting means for detecting nuclear magnetic resonance signals emitted from the object, control means for controlling the magnetic field generating means and detecting means, computing means for visualizing morphology or functions of  
10 the examined object using the nuclear magnetic resonance signals detected by the detecting means, and display means for displaying the computed results as images,

wherein the control means operates so that a step of acquiring a plurality of nuclear magnetic resonance signals  
15 as image-forming data at one excitation is performed continuously and, during the continuing step, a step of acquiring correction data plural times at a desired interval is performed,

and the computing means comprises means for producing  
20 a correction data group, which includes temporal variations in the interval, using a plurality of the correction data acquired at a desired interval and means for correcting the image-forming data using correction data from among the correction data group, which corresponds to acquisition  
25 time of the image-forming data.

2. A magnetic resonance imaging method comprises a step A of acquiring image-forming data consisting of a plurality of nuclear magnetic resonance signals at one excitation, a step B of repeating the step A while changing

a slice-encoding gradient magnetic field and/or phase-encoding gradient magnetic field, a step C of repeatedly acquiring correction data at a desired interval during repetition of the step A, a step D of producing correction data corresponding to acquisition time of image-forming data acquired between acquisitions of one correction data and next correction data using at least two correction data, and a step E of performing phase-correction of the image-forming data using correction data corresponding to acquisition time of the image-forming data from among the correction data produced in the step D.

3. The magnetic resonance imaging method of claim 2, wherein plural image-forming data are acquired between acquisitions of one correction data and the next correction data, and the correction data produced in the step D is a group of plural correction data corresponding to the plural image-forming data.

4. The magnetic resonance imaging method of claim 2, wherein the step B is performed with a significantly shorter repetition time TR than a longitudinal relaxation time of the examined object.

5. The magnetic resonance imaging method of any one of claims 2-4, wherein the step D produces the correction data using a raw correction data acquired in the step C.

6. The magnetic resonance imaging method of any one of claims 2-4, wherein the step D produces the correction data after a raw correction data acquired in the step C is subjected to a Fourier transform in the readout direction.

7. A magnetic resonance imaging apparatus comprising

magnetic field generating means for producing nuclear magnetic resonance in an object to be examined, detecting means for detecting nuclear magnetic resonance signals emitted from the object, control means for controlling the magnetic field generating means and detecting means, computing means for visualizing morphology or functions of the examined object using the nuclear magnetic resonance signals detected by the detecting means, and display means for displaying the computed results as images,

10            wherein the control means performs pre-scan for  
acquiring data for correcting variations of eddy currents  
and/or inhomogeneities in the static magnetic field  
according to a time constant prior to a main measurement  
scan, and the computing means corrects data obtained by the  
15 main measurement scan based on the data obtained by the  
pre-scan.

8. A magnetic resonance imaging apparatus of claim 7, wherein the control means performs the pre-scan so that the data is acquired without a phase-encoding gradient magnetic field of the main measurement scan or with a readout gradient magnetic field having a reversed polarity, and the computing means produces phase data for each acquisition time of the main scan data using the pre-scan data and corrects the main scan data using the phase data.

25           9. A magnetic resonance imaging apparatus comprises magnetic field generating means for producing nuclear magnetic resonance in an object to be examined, detecting means for detecting nuclear magnetic resonance signals emitted from the object, control means for controlling the



magnetic field generating means and detecting means, computing means for visualizing morphology or functions of the examined object using the nuclear magnetic resonance signals detected by the detecting means, and display for  
5 displaying the computed results as images,

wherein the control means acquires a plurality of correction data at a predetermined interval and acquires image-forming data continuously between acquisitions of the correction data, and the computing means produces a  
10 correction data group, which corresponds to acquisition time of the image-forming data, using the correction data and corrects the image-forming data using the correction data group for each corresponding acquisition time.

10. The magnetic resonance imaging apparatus of claim  
15 9, wherein the computing means reverses data arrangement corresponding to the polarity of gradient magnetic field pulses after acquisition of the image-forming data.

11. The magnetic resonance imaging apparatus of claim  
20 9, wherein a plurality of image-forming data acquired continuously between acquisitions of the correction data by the control means corresponds to one image.

12. The magnetic resonance imaging apparatus of claim  
11, wherein a plurality of image-forming data acquired continuously between acquisitions of the correction data by  
25 the control means is for an identical slice and two-dimensional images of the slice are displayed successively on the display means.

13. The magnetic resonance imaging apparatus of claim  
11, wherein a plurality of image-forming data acquired

continuously between acquisitions of the correction data by the control means is for different slices, and two-dimensional images of the plural slices are displayed simultaneously on the display means.

5           14. The magnetic resonance imaging apparatus of claim 11, wherein a plurality of image-forming data acquired continuously between acquisition of the correction data by the control means is for adjacent slices, and the computing means produces a three-dimensional image using two-  
10       dimensional image data and displays the tree-dimensional image on the display means.

15           15. A magnetic resonance imaging method of detecting nuclear magnetic resonance signals emitted from an object to be examined, imaging morphology or functions of the  
15       object using the nuclear magnetic resonance signals and displaying the computed results as images, comprises the steps of;

              acquiring correction data at a predetermined interval,  
              acquiring image-forming data continuously between  
20       acquisitions of the correction data,

              producing a correction data group corresponding to acquisition time of the image-forming data using the correction data,

              and correcting the image-forming data using the  
25       correcting data group for each corresponding acquisition time.

              16. A magnetic resonance imaging method comprising;  
              a step of continuously acquiring image-forming data consisting of a plurality of nuclear magnetic resonance

signals while changing a slice-encoding gradient magnetic field or a phase-encoding gradient magnetic field,

5 a step of repeatedly acquiring correction data at a desired interval during acquisition of the image-forming data,

a step of producing a correction data group including temporal variations between acquisitions of one correction scan data and the next correction scan data using at least two correction data, and

10 a step of performing phase correction of the image-forming data using correction data corresponding to acquisition time of the image-forming data from among the correction data group.

# ABSTRACT

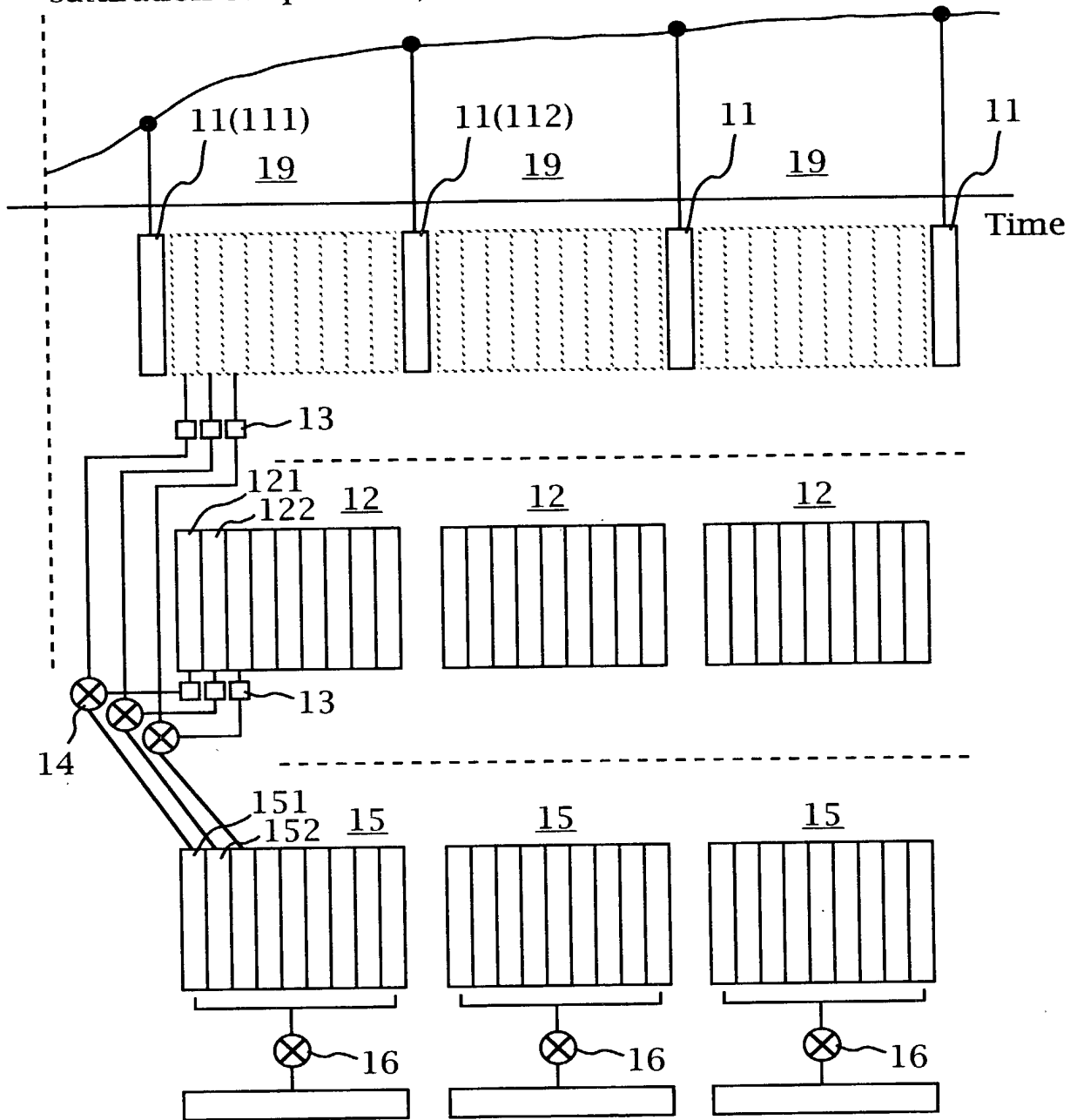
When a series of main scan data is obtained by continuously acquiring image-forming data consisting of a plurality of nuclear magnetic signals, a plurality of correction data is acquired at a predetermined interval. Using the correction data, a correction data group corresponding to acquisition time of the image-forming data is produced and the image-forming data is corrected using the correction data group for each acquisition time. Thus, the image-forming data is corrected by a estimated phase rotation amount at a time of acquisition and consequently stable MR images can be obtained even under a condition where phase variations of signals change over time accompanied with changes of eddy currents and spin saturation.

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Fig.1

physical conditions

(eddy currents of the apparatus, magnetic field variation, saturation of spins etc.)



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Fig.2

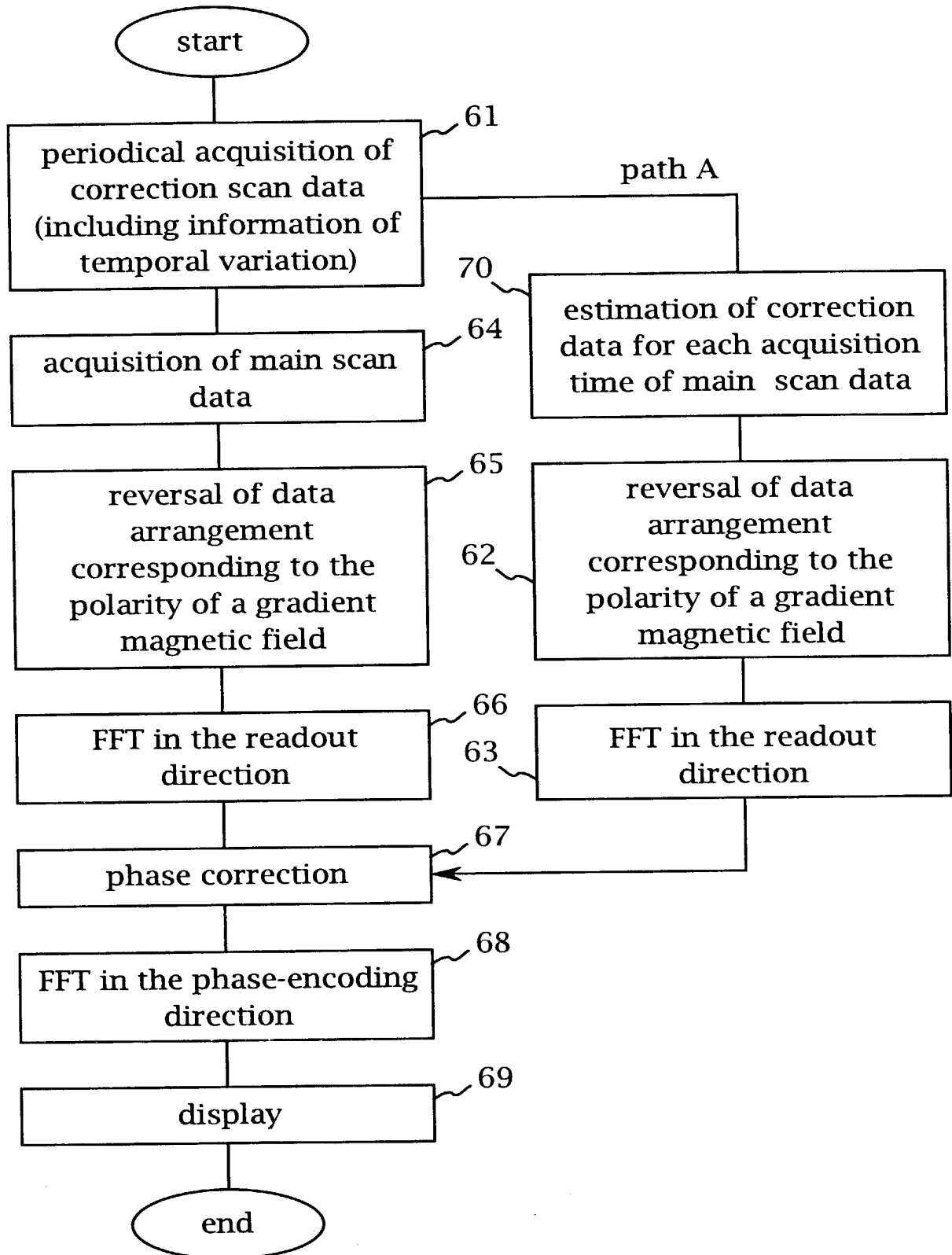
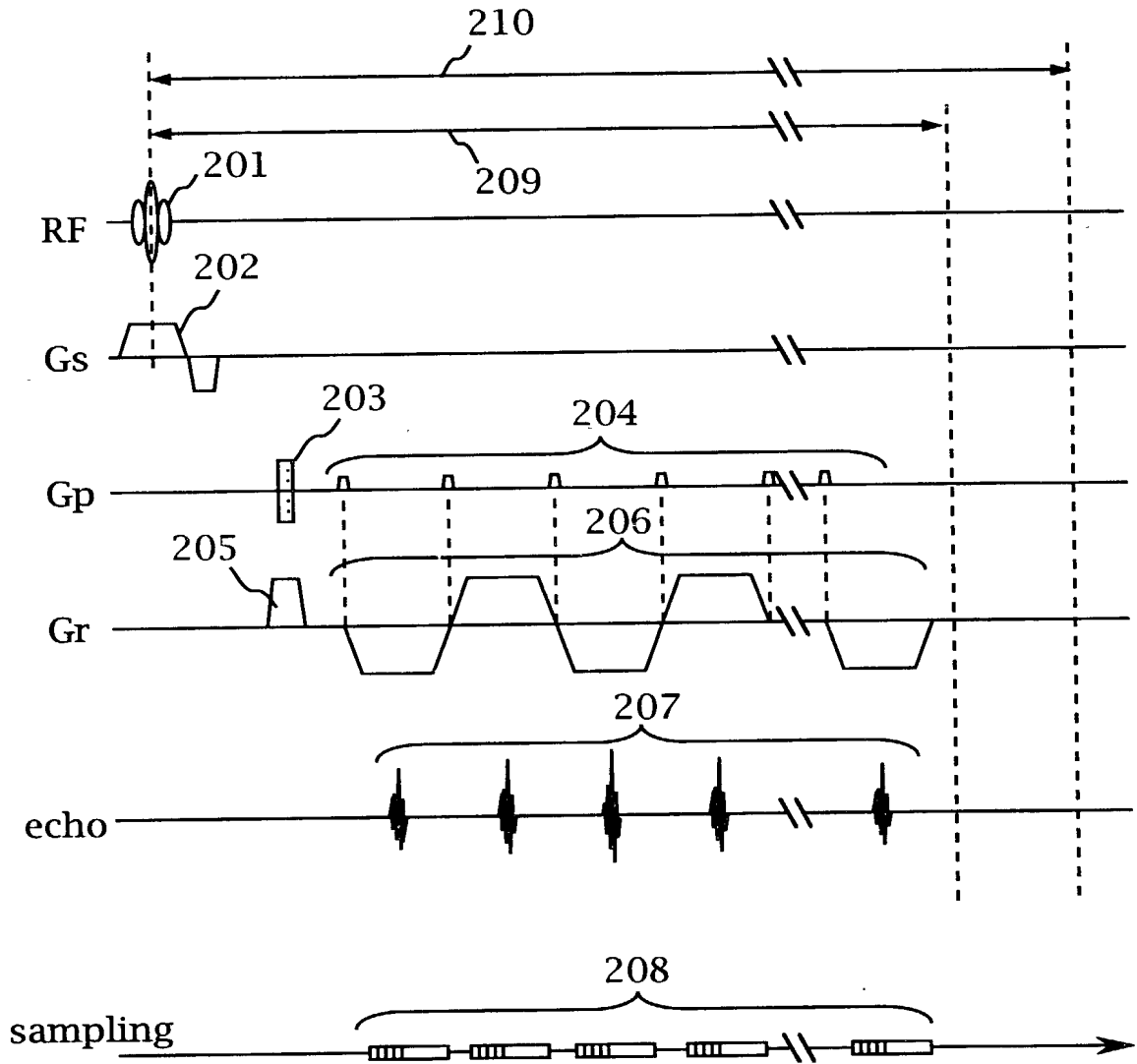
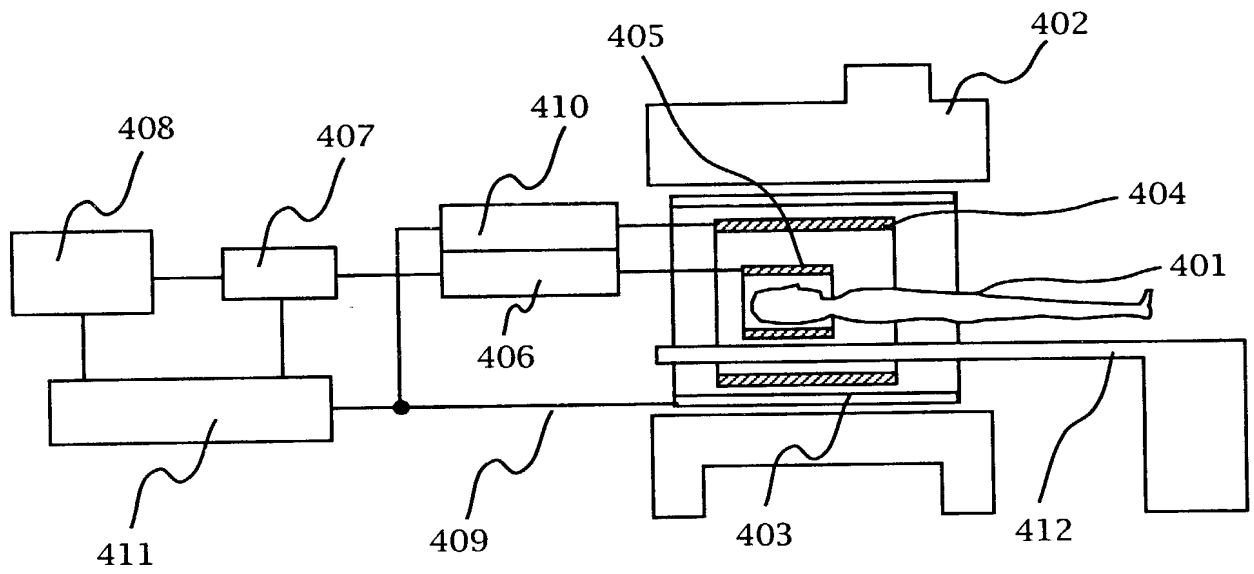


Fig.3



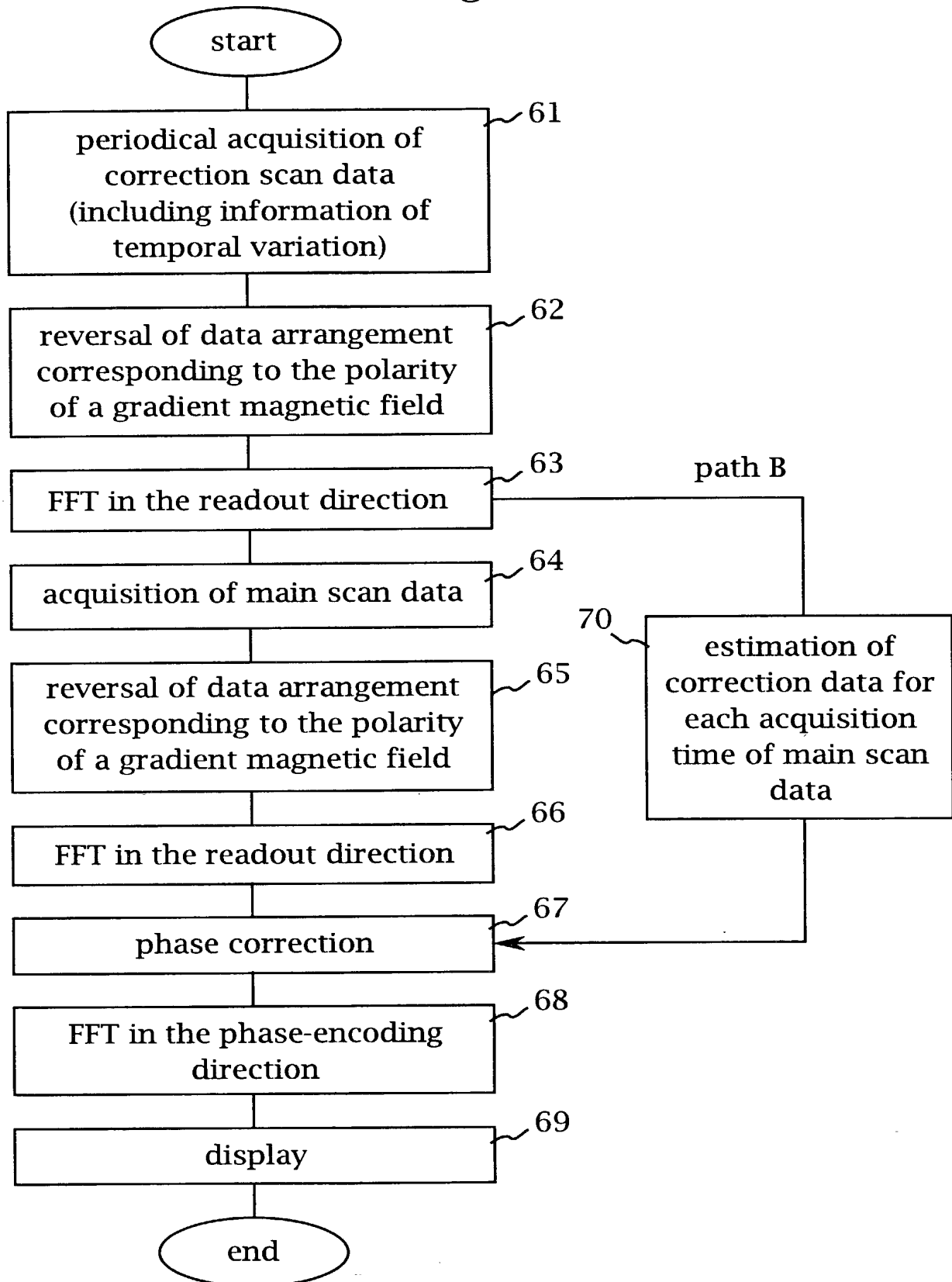
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Fig.4





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Fig.5

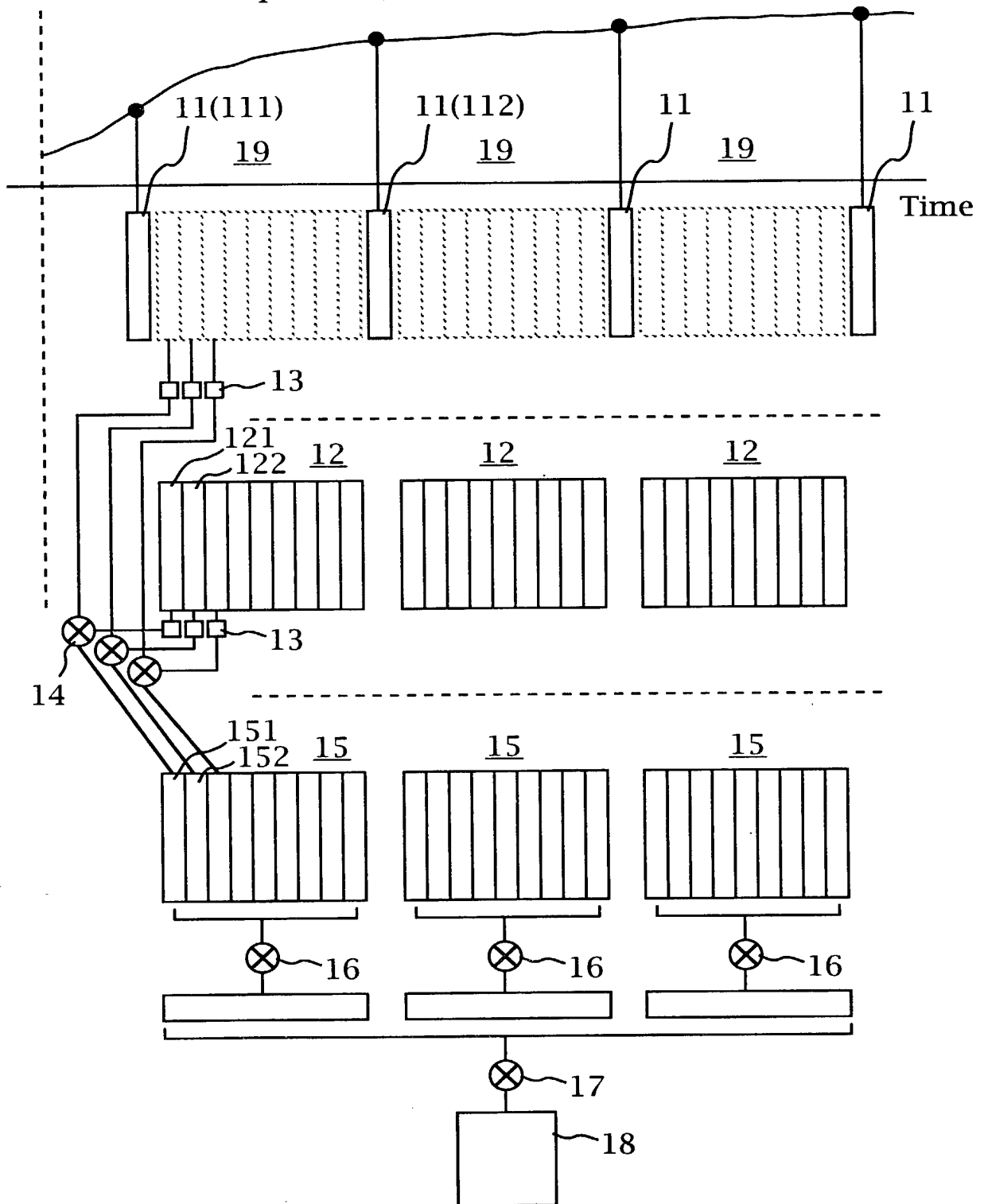


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Fig.6

physical conditions

(eddy currents of the apparatus, magnetic field variation, saturation of spins etc.)



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外国での先行出願

PCT/JP00/6721

(Number)

(番号)

11-281293

(Number)

(番号)

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Priority Not Claimed

優先権主張なし

28/9/2000

(Day/Month/Year Filed)

(出願年月日)

1/10/1999

(Day/Month/Year Filed)

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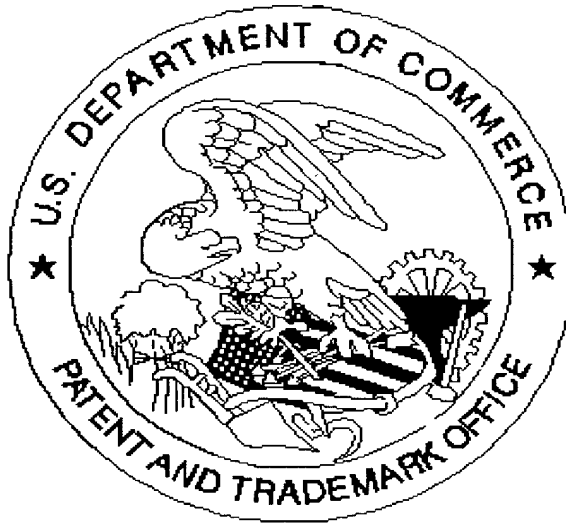
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